

FINAL TECHNICAL REPORT – The Bermuda BioOptics Project (BBOP) Years 9-11
 NASA CONTRACT NAS5-00200

5. Science Team Introduction (Bio-optical, Atm. & International)

_. Bermuda Bio Optics Project, Norm Nelson, PI

_.1 Introduction

The Bermuda BioOptics Project (BBOP) is a collaborative effort between the Institute for Computational Earth System Science (ICESS) at the University of California at Santa Barbara (UCSB) and the Bermuda Biological Station for Research (BBSR). This research program is designed to characterize light availability and utilization in the Sargasso Sea, and to provide an optical link by which biogeochemical observations may be used to evaluate bio-optical models for pigment concentration, primary production, and sinking particle fluxes from satellite-based ocean color sensors. The BBOP time-series was initiated in 1992, and is carried out in conjunction with the U.S. JGOFS Bermuda Atlantic Time-series Study (BATS) at the Bermuda Biological Station for Research. The BATS program itself has been observing biogeochemical processes (primary productivity, particle flux and elemental cycles) in the mesotrophic waters of the Sargasso Sea since 1988. Closely affiliated with BBOP and BATS is a separate NASA-funded study of the spatial variability of biogeochemical processes in the Sargasso Sea using high-resolution AVHRR and SeaWiFS data collected at Bermuda (N. Nelson, P.I.). The collaboration between BATS and BBOP measurements has resulted in a unique data set that addresses not only the SIMBIOS goals but also the broader issues of important factors controlling the carbon cycle.

_.2 Research activities

BBOP personnel participate on all BATS cruises, which are conducted monthly with additional cruises during the spring bloom period, January through May. Table 1 contains a list of data products relevant to SIMBIOS. The BBOP project collects continuous profiles of apparent optical properties (AOPs) in the upper 140m and deployments are planned to optimize match-ups with the BATS primary production incubations and with SeaWiFS overpasses. In 1999, a free-falling Atlantic profiling radiometer system (SPMR/SMSR s/n 028) became our primary profiling instrument. The primary optical measurements are downwelling vector irradiance and upwelling radiance, $E_d(z,t,\lambda)$ and $L_u(z,t,\lambda)$, respectively. Derived products include remote sensing reflectance ($R_{rs}(z,\lambda)$) and down- and upwelled attenuation coefficients ($K_d(z,\lambda)$, $K_u(z,\lambda)$). The sampling package also includes a second mast-mounted radiometer with wavebands matching those on the underwater instrument for measuring incident downwelling vector irradiance, $E_d(0^+,t,\lambda)$. The instruments are calibrated three times annually at UCSB. Sky radiance measurements were collected early in the year, but the Microtops photometer began malfunctioning and it was returned to the project in the spring of 2003.

Bottle samples for fluorometric chlorophyll-*a* and inherent optical properties (IOPs) are also collected. Chlorophyll-*a* is collected once or twice daily during each cruise. Discrete samples for determining the absorption spectra of particulates, $a_{ph}(z,\lambda)$ and $a_d(z,\lambda)$, and CDOM ($a_g(z,\lambda)$) are collected according to Nelson *et al* (1998). Particulate absorption spectra are determined using

the quantitative filter technique (Mitchell, 1990) (with a regionally specified beta correction factor) and CDOM absorption according to Nelson *et al* (1998). During the past year, BBOP has participated in 14 BATS cruises. We have submitted 260 optics profiles, 70 fluorometric Chlorophyll-a profiles, 150 IOP spectra, and 4 Microtops scans for sky radiance.

3 Research results

Instrument Calibration

We have continued our documentation of the long-term calibration behavior of our SPMR systems using several lamps traceable to our own NIST standard. Channels greater than 500nm continue to show no obvious drift, and overall scatter is ~1% and ~2% for irradiance and radiance detectors, respectively. The coefficients of variation these channels are less than 1%. In general, the radiance channels are more stable than the irradiance channels. This suggests that the fault is most likely to be the materials used in the cosine collectors. The tendency for the UV and blue channels to vary more than the red is in part due to the lower output of calibration lamps at lower wavelengths. The most extreme changes were noted at the shortest UV channels in both irradiance heads: up to 50-60% for Ed325 and Es325, and about half that for Ed340 and Es340. It appears that this decrease in sensitivity occurred during the first year, and that these sensors are now stable, although the response is still quite variable. The additional year of data now shows that two UV radiance and the blue irradiance channels have undergone significant drift toward lower sensitivity. The drift in the blue radiance sensors was less apparent, and smaller, about 1-2%, not significantly different from variation observed in the green-red channels. All affected data for these channels was recalculated using a predicted coefficient rather than a long-term average, and resubmitted.

Collaborative and Project-Related Activities

As in past years, the BBOP data set 1) contributed to the validation of satellite data products within in the SIMBIOS project and 2) used to make original contributions to scientific literature. In particular, BBOP is among the clearest ocean sites observed within the SIMBIOS program on a consistent basis. This means that BBOP has consistently been the clear water end member in match-up analyses made between field and satellite observations. The present version (August 2003) of the SIMBIOS SeaWiFS LAC-field observation match-up data set (Bailey *et al.* 2000) contains 383 independent field and satellite observations of water-leaving radiance. Thirty of these observations are from the BBOP project. As always these data are available via the world wide web (www.ices.ucsb.edu/bbop.html).

A primary science result from BBOP has been the observation that the optical properties of open ocean are greatly affected by concentrations of colored dissolved organic materials or CDOM (Siegel and Michaels, 1996; Nelson *et al.* 1998; Nelson and Siegel, 2002; Siegel *et al.* 2002). We have shown that CDOM dominates the optical properties in the blue region of the spectrum using knowledge gained at BBOP and available field and satellite data sets (many field observations were supported by the SIMBIOS program). Globally, 45% of the non-water absorption at 440 nm is due to CDOM (Siegel *et al.* 2002). Retrieval algorithms for CDOM were developed (Maritorena *et al.* 2002) and used to assess its global distribution and variability (Siegel *et al.* 2002). We have recently shown that the open ocean source of CDOM is the heterotrophic cycling of DOM by bacteria (Nelson *et al.* 2003) where CDOM can be created and destroyed by microbes. The interesting result from these microbe batch culture experiments is

that the net CDOM produced mirrors the “complexity” of the DOM source (i.e., high molecular weight DOM leads to more long-lasting CDOM produced). We are presently testing these hypotheses on a new project looking at open ocean CDOM cycling supported by NSF.

Our work on CDOM has lead us to consider its interactions with other photoactive materials. One interesting candidate is dimethyl sulfide (DMS). Using existing time series (Dacey et al. 1998) and new experimental data, we have calculated the rates that DMS is photolysed by exposure to ultraviolet radiation (Toole et al. 2003). Using these results and new observations of microbial DMS (and DMSP) cycling by bacteria, we have made new and important estimates of the biological cycling of DMS (Toole and Siegel, 2003). Our supports the notion that DMS is important as an intracellular anti-oxidant removing radicals and superoxides within a cell. (Sunda et al. 2002). These results have a critical bearing on how climate feedbacks due to marine emissions of DMS might occur (Toole and Siegel, 2003).

5 References

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Toole, D.A., D.J. Kieber, R.P. Kiene, D.A. Siegel and N.B. Nelson, 2003: Photolysis and the dimethylsulfide (DMS) summer paradox in the Sargasso Sea. *Limnology and Oceanography*, **48**, 1088-1100.

7 Tables

TABLE 1: PARTIAL LIST OF MEASUREMENTS MADE BY BBOP & BATS

BBOP	
Direct Measurements:	
$E_d(z, \lambda)$	Downwelling vector irradiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$E_d(0^+, \lambda)$	Incident irradiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$L_u(z, \lambda)$	Upwelling radiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
chl-fl(z)	Chlorophyll fluorescence with a WetStar fluorometer
T(z) & S(z)	Temperature and conductivity with Ocean Sensors probes (calibrations by Satlantic)
$a_{tp}(\lambda)$	Particulate absorption spectrum by QFT
$a_d(\lambda)$	Detrital particle absorption spectrum by MeOH extraction
$a_{ys}(\lambda)$	Colored dissolved absorption spectrum
chl-a(z)	Discrete chlorophyll <i>a</i> determinations via Turner fluorometry
Primary Derived Products:	
$L_{WN}(\lambda)$	Normalized water leaving radiance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$R_{RS}(0^-, \lambda)$	In-water remote sensing reflectance (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$K_d(z, \lambda)$	Attenuation coefficient for $E_d(z, \lambda)$ (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$K_l(z, \lambda)$	Attenuation coefficient for $L_u(z, \lambda)$ (325, 340, 380, 412, 443, 488, 510, 555, 565, 665 & 683 nm)
$a_{ph}(\lambda)$	Phytoplankton absorption spectrum ($= a_p(\lambda) - a_{det}(\lambda)$)
$\langle PAR(z) \rangle$	Daily mean photosynthetically available radiation at depths of the <i>in situ</i> C ¹⁴ incubations
U.S. JGOFS BATS (NSF) AND RELATED BIOGEOCHEMISTRY SAMPLING PROGRAMS	
Primary Production (<i>in situ</i> ¹⁴ C incubation)	Sinking flux (sediment trap array)
Phytoplankton pigments (fluorometric & HPLC)	Nutrients (NO ₃ +NO ₂ , SiO ₄ , PO ₄)
CO ₂ system (alkalinity, TCO ₂ and pCO ₂)	Continuous atmosphere & surface pCO ₂
Dissolved oxygen (continuous & discrete)	Zooplankton biomass & grazing
POC & PON (POP infrequently)	DOC & DON (DOP infrequently)
Full water column, WOCE-standard CTD profile	Bacterial abundance and rates
Validation spatial cruises (5 days, 4cruises/year)	Deep ocean sediment sinking fluxes

TABLE 2: PAPERS AND PRESENTATIONS DURING THE PREVIOUS YEAR:

Published or in press

Siegel, D.A., S. Maritorena, N. B. Nelson, D.A. Hansell and M. Lorenzi-Kayser, 2002: Global ocean distribution and dynamics of colored dissolved and detrital organic materials. *Journal of Geophysical Research*, **107**, 3228, DOI: 10.1029/2001JC000965.

Chomko, R.M., H.R. Gordon, S. Maritorena and D.A. Siegel, 2003: Simultaneous determination of oceanic and atmospheric parameters for ocean color imagery by spectral optimization: a validation. *Remote Sensing of the Environment*, **84**, 208-220.

Westberry T.K., and D.A. Siegel, 2003: Phytoplankton natural fluorescence in the Sargasso Sea: Prediction of primary production and eddy induced nutrient fluxes. *Deep-Sea Research, Part I*, **50**, 417-434.

Toole, D.A., D.J. Kieber, R.P. Kiene, D.A. Siegel and N.B. Nelson, 2003: Photolysis and the dimethylsulfide (DMS) summer paradox in the Sargasso Sea. *Limnology and Oceanography*, **48**, 1088-1100.

Nelson, N.B., C.A. Carlson, and D.A. Steinberg. 2003, Production of chromophoric dissolved organic matter by Sargasso Sea microbes. In press, *Marine Chemistry*.

Nelson, N.B., D.A. Siegel, and J.A. Yoder, 2003, The spring bloom in the northwestern Sargasso Sea: Spatial extent and relationship with winter mixing. Accepted for publication in *Deep-Sea Research, Part II*.

Submitted

Behrenfeld, M.J., E. Boss, D.A. Siegel and D.M. Shea, 2003, Global remote sensing of phytoplankton physiology. Submitted to *Science*.

Toole, D.A., and D.A. Siegel, 2003: Light and the open ocean cycling of dimethyl sulfide (DMS). Submitted to *Nature*.

Presentations

Toole, D.A., R.P. Kiene, and D. Slezak, D.J. Kieber, and D.A. Siegel, Rates and Quantum Yields of Dimethylsulfide Photo-oxidation in the Western Atlantic Ocean, 2002 3rd international symposium on biological and environmental chemistry of DMS(P) and related compounds, September 2002, Rimouski, Quebec, Canada, poster presentation.

Maritorena, S., D.A. Siegel and D.B. Court, 2002: Ocean color data merging using a semi-analytical model. Poster presented at the Ocean Optics XIII meeting, Sante Fe, NM, November 2002.

Westberry, T., D.A. Siegel and A. Subramaniam, 2002: New techniques for the remote sensing of Trichodesmium. Poster presented at the 2002 AGU Fall Meeting, San Francisco, CA, December 2002.

Toole, D.A., D.A. Siegel, D. Slezak, R.P. Kiene, N.B. Nelson and J.W. Dacey, 2002: A light driven upper-ocean dimethylsulfide (DMS) biogeochemical cycling model for the Sargasso Sea. Poster presented at the 2002 AGU Fall Meeting, San Francisco, CA, December 2002.

Siegel, D.A., J.C. Ohlmann, S.C. Doney, C.R. McClain, 2002: Variability of ocean radiant heating in the Eastern Tropical Pacific. Poster presented at the 2002 AGU Fall Meeting, San Francisco, CA, December 2002.

Siegel, D.A., 2003: Sverdrup's critical depth hypothesis and the North Atlantic spring bloom. Presentation made for the International JGOFS North Atlantic Synthesis Group, Toulouse, FR., January 2003.

- Klamberg, J.L., N.B. Nelson and D.A. Siegel, 2003: One-dimensional modeling of seasonal colored dissolved organic matter dynamics in the Sargasso Sea. Poster presented at the 2003 ASLO Aquatic Sciences meeting, Salt Lake City, UT, February 2003.
- Siegel, D.A., N.B. Nelson, S. Maritorena, C.A. Carlson, A.F. Michaels, D.A. Hansell and D.K. Steinberg, 2003: Distribution, dynamics and biogeochemical implications of colored dissolved organic materials in the open ocean. Poster presented at the NASA Ocean Color Science Team Meeting, Miami FL, April 2003.
- Maritorena, S., D.A. Siegel and D.B. Court, 2003: Ocean color data merging using a semi-analytical model. Poster presented at the NASA Ocean Color Science Team Meeting, Miami FL, April 2003.
- Siegel, D.A., 2003: Reenvisioning the Ocean: The View from Space A RESPONSE, Invited rebuttal presented at the JGOFS Open Science Conference, Washington DC, May 2003.
- Siegel, D.A., N.B. Nelson, S. Maritorena, C.A. Carlson, A.F. Michaels, D.A. Hansell and D.K. Steinberg, 2003: Distribution, dynamics and biogeochemical implications of colored dissolved organic materials in the open ocean: discoveries made during the JGOFS era. Poster presented at the JGOFS Open Science Conference, Washington DC, May 2003.
- North Atlantic Synthesis Group (a total of 9 including Siegel), 2003: Time series and process study sites in the North Atlantic during the JGOFS decade. Poster presented at the JGOFS Open Science Conference, Washington DC, May 2003.
- North Atlantic Synthesis Group (a total of 9 including Siegel), 2003: Large scale biogeochemical diagnostics: the North Atlantic carbon machinery. Poster presented at the JGOFS Open Science Conference, Washington DC, May 2003.
- North Atlantic Synthesis Group (a total of 9 including Siegel), 2003: Modeling and data assimilation in the North Atlantic: Towards GODAE. Poster presented at the JGOFS Open Science Conference, Washington DC, May 2003.

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